

UNITED NATIONS GENERAL ASSEMBLY



Distr.
GENERAL

A/AC.105/563
23 December 1993

ORIGINAL: ENGLISH

COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE
Scientific and Technical Subcommittee
Thirty-first session
Vienna, 21 February-4 March 1994

SPACE APPLICATIONS FOR FOREST RESOURCE MANAGEMENT

Note by the Secretariat

1. The Working Group of the Whole to Evaluate the Implementation of the Recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82), at its seventh session (A/AC.105/543, annex II, para. 17), recommended that several studies on space applications should be carried out to demonstrate the potential of space technology. The Working Group of the Whole identified a number of possible subjects for such studies, including forest resource management.
2. The report of the Working Group of the Whole was adopted by the Scientific and Technical Subcommittee at its thirtieth session (A/AC.105/543, para. 22), and the recommendations contained in the report were endorsed by the Committee on the Peaceful Uses of Outer Space at its thirty-sixth session¹ and by the General Assembly in its resolution 48/39 of 10 December 1993.
3. In response to the request of the Working Group of the Whole, the Secretariat prepared a study on space applications for forest resource management. The study, which is available in English only, is presented in the annex to the present note. The purpose of the study was to provide a review of the applications of space technology for forest resource management, primarily for the benefit of countries that had not yet used space technology for that purpose but were interested in its potential benefits. A summary of the study is provided below.

SUMMARY OF THE STUDY

4. Remote sensing is a highly cost-effective technology for planning and managing natural resources such as forests. Remotely sensed data from a number of satellites are now being made available to every country. A large number of digital data processing techniques and software packages have been developed to enable these data to be used for various resource inventory and management purposes. In countries with vast forest areas, such as Canada, remote sensing and Geographic Information Systems (GIS) are among the everyday tools used to monitor and manage forest resources.
5. Satellite remote sensing is particularly valuable for repetitive coverage of large areas where aerial or ground surveys may be too slow and expensive. This technology is used primarily for mapping the environment and natural resources. Features that are readily visible on satellite images include forests, cities, rivers and streams, grasslands and cultivated fields. Remote sensing can provide information necessary for forest resource assessment and it can be a valuable aid in making decisions related to forest management.

6. There is a lack of reliable, up-to-date information on forest resources in most developing countries. In some cases, even the figures on the total forested area are in dispute. Although in developed countries total forest resources are quantified to a large extent, vast areas are subject to industrial pollution such as acid rain. Under such circumstances, it is not surprising that the rate of forest depletion is much higher than earlier projections.

7. The loss of tropical forests is currently one of the most serious environmental threats. Despite the significant importance of forests to people, it is estimated that more than 11 million hectares are destroyed every year. More than half of the world's tropical forests have disappeared since the beginning of the twentieth century and an incalculable number of trees have been lost because of forest degradation, over-exploitation for timber and fuelwood, overgrazing by livestock, and other non-suitable land-use practices.

8. Deforestation, particularly in developing countries, has a dramatic impact on food production, fuelwood and fodder supplies, soil fertility and water resources. The result of extensive forest destruction is the loss of biological diversity and the forest gene pool, which has been and still is crucial to the supply of basic genetic material that makes up many important food products and medicines.

9. Furthermore, uncontrolled deforestation changes the water balance, leading to climatic changes via decreased evapotranspiration, reductions in rainfall, further loss of moisture in tropical forests and downstream flooding along densely populated river corridors. Moreover, forest destruction increases carbon dioxide concentrations in the atmosphere, which, in the opinion of a large part of the scientific community, has led to temperature increases over the past century via the greenhouse effect.

10. Deforestation also threatens sustainable economic development of developing countries through the loss of foreign trade. Forests provide developing countries with an important source of foreign exchange for potentially renewable resources, and many countries, such as Indonesia, Malaysia and the Philippines, rely heavily on timber exports to finance their economic development.

11. Consequently, there is growing concern that the rapid depletion of forest resources may induce serious setbacks in the short-term export value of forest products. Moreover, it may result in a declining productive employment rate, because wood, both as a raw material and as a fuel used in industry, is becoming more scarce and therefore expensive.

12. One of the primary measures that should be implemented to improve forest management and possibly stop or reverse the above-mentioned trends is the development of techniques that provide rapid and accurate information about forest conditions. Thus, in the assessment of forests for their productivity and sustainability, it is important to be able to measure relevant parameters at recurring intervals.

13. It is difficult to collect reliable forest data on the large scale needed to determine the extent of deforestation and the best policies in managing forest resources. In many cases, traditional sources of information, such as field and aerial surveys, are too time-consuming and expensive. One solution that is becoming increasingly operational involves taking advantage of the synoptic coverage that can be provided by Earth observation satellites. It has become apparent that only by using data from such satellites will it be possible to monitor and quantify forest resources when whole countries or continents are involved.

14. By observing the Earth using the capabilities of both meteorological and remote-sensing satellites, it is possible to map worldwide natural resources and to monitor the environment. The new generation of radar satellites is expected to make a major contribution to the data archive and to the global knowledge of the state of tropical forests.

15. The first European Remote Sensing Satellite (ERS-1) and the first Japan Earth Resources Satellite (JERS-1) have already begun to transmit to Earth images obtained in the microwave region of the electromagnetic spectrum. In this region, microwave radiation passes through clouds with negligible attenuation; thus, it is possible to monitor the tropical areas, which are frequently covered by clouds, in any kind of weather.

16. Data processing and analysis techniques have been developed to handle the large amounts of data obtained from each satellite image. These same techniques and the continuing improvement of computing capacity per unit cost make it possible to integrate other ancillary data (topographic maps, mean rainfall, average hours of sunlight etc.), which would be burdensome if not impossible to do using conventional techniques.

17. Computer-based Geographic Information Systems have been developed and are being applied to assist in the integration and analysis of natural resource data. These systems have been designed to make it possible to carry out fast comparative analyses of previously stored resource data and other cartographic data. Forest resource managers and planners can use those data and combine them with satellite imagery to generate custom-made maps and statistics that respond to specific situations when they arise.

18. Satellite remote sensing and GIS are foremost among the new essential technologies for sustainable forest management and environmental protection. To maintain the fragile balance between economic development and environmental quality, developing countries need assistance in strengthening their indigenous capacities in the use of advanced technologies for sustainable management of renewable resources and environmental protection.

Note

¹Official Records of the General Assembly, Forty-eighth Session, Supplement No. 20 (A/48/20), para. 25.

Annex

FOREST RESOURCE MANAGEMENT

Study by the Secretariat*

CONTENTS

	<u>Paragraphs</u>	<u>Page</u>
INTRODUCTION	1-10	5
I. SPACE BASED SENSORS FOR MONITORING FORESTS	11-33	6
II. FOREST RESOURCE ASSESSMENT	34-65	9
A. Forest Inventories	34-47	9
B. Damage Assessment	48-61	11
C. Productivity Assessment	62-65	13
III. RESOURCE MANAGEMENT AND ENVIRONMENTAL MONITORING ..	66-102	13
A. Forest Management	66-73	13
B. Fuel Wood Supply	74-83	14
C. Monitoring and Controlling Deforestation	84-94	15
D. Environmental Monitoring	95-102	16
IV. FUTURE PROSPECTS	103-106	17

*The present study has not been edited.

INTRODUCTION

1. The Earth is a finite planet with limited resources. As the population continues to grow, placing ever increasing pressures on the environment and its resources, wise and prudent planning becomes increasingly important. Remote sensing from space depicts a new potential to produce and maintain consistent data sets (with adequate spatial, temporal and spectral resolutions), for environmental and resource inventories.
2. The world's forests are under intense pressure. The demand for timber and fuelwood is ever increasing, particularly because wood is the primary indigenous energy source for many developing countries. Thus, it is of primary importance to know the amount of existing woodland, forest and bush area, along with the rates of depletion and the location of depleted reserves. As a follow up, management plans can be implemented to ensure that this natural resource is sustained.
3. Forest products are also a crucial element in the export economy of many developing countries. Thus, it is of primary importance to maintain a successful forest industry and to balance the rate of forest removal with the rate of regrowth. Remote sensing data are the only realistic tool to monitor forest resources. An unmanaged forest resource leads to uncontrolled deforestation, which in turn causes environmental instability and therefore, continues the process of hazardous soil erosion and desertification.
4. Remote sensing alludes to the acquisition of information about an object without being in physical contact with it. The term, however, is commonly used to describe the process of gathering information about the earth surface, through data acquired by aircraft or satellite. This data acquisition is conducted with a variety of sensors, including photographic cameras, electronic multi-spectral scanners operating in the visible and infrared regions of the electromagnetic spectrum and imaging radar systems.
5. In deciding between the use of a satellite remote sensing imaging system for forest applications as opposed to aircraft or conventional ground techniques, it is important to understand that extensive and repetitive coverage of the surface of the Earth can only be economically provided by satellite systems. In fact, the use of aerial photography covering an area equal to a satellite image would lead to an enormous increase in cost.
6. The present report focuses on the use of data from active and passive satellite remote sensing systems such as ERS 1 (active) and SPOT and Landsat (passive) for forest applications. Passive remote sensing systems rely on reflected solar energy to discriminate between objects on the ground while active systems generate their own source of energy. Although the new generation of earth observation satellites have an increased spatial resolution, in specific cases they may need to be combined with conventional techniques to obtain the required information for particular purposes.
7. Although users have access to an immense amount of data generated by remote sensing satellite systems, that could provide solutions to many forest management problems, in and of itself, the sheer volume of generated data also creates problems. The user community is confronted with an increasing number of satellite and data processing systems and, due to increased resolution, an enormous data storage problem. This study will therefore examine aspects of data integration from different sources and their use in Geographical Information Systems (GIS).
8. The analysis of remote sensing data can be enhanced in terms of accuracy and level of classification if digital image processing techniques are used. These include radiometric and geometric corrections of data, specific enhancement of the imagery to enable maximum differentiation of the required forest types for subsequent visual interpretation or for computer aided classification.

9. Presently, in most countries of the developing world the equipment and skills required for regular monitoring of forest resources are not available. Therefore, the strengthening of indigenous remote sensing and GIS capacities in developing countries should be one of the prime objectives of the national authorities responsible for providing the country with adequate tools for continuous monitoring and sustained management of tropical forests.

10. The present study will concentrate on the unique ability of satellite Earth observation to provide a global picture of natural phenomena having an impact on forests and, it will examine the role of forests as the "lungs" of the atmosphere. Concerns over uncontrolled exploitation, deforestation and the ability of remote sensing to overcome these problems will be considered as well.

I. SPACE BASED SENSORS FOR MONITORING FORESTS

11. Until the end of the 1960s, the only remote sensing system used in forestry was the aerial photographic camera. Since then, new platforms, sensors and techniques have been introduced. These systems, complementary to aerial photography, differ widely in cost and in technical parameters. These include airborne and space borne cameras and spectral scanners as well as imaging radar.

12. Placement in orbit of space based remote sensing sensors for Earth observation became operational with the introduction of the Landsat resource survey system. Since Landsat's launch in 1972, satellite remote sensing data have been available on a worldwide basis with increasing spatial and spectral resolution. In 1986, the first of the French satellite SPOT series was launched. Both of the original Landsat and SPOT satellites have been replaced by a series of satellites equipped with new sensors representing the current state of the art in technology. With repeat-visit periods of 16 days for Landsat and 26 days for SPOT, these sensors provide regular coverage of the Earth's surface, excluding the regions immediately around the poles.

13. Although satellite images often appear like photographs, the acquisition of these data is quite different from conventional photographic processes. The complete sensor system may consist of a rotating mirror or prism which directs the electromagnetic radiation coming from a scanned path to an optical system that focuses the radiation on sets of detectors. These detectors convert the electromagnetic energy received into an electrical signal which is recorded on board the satellite digitally. As the satellite passes over one of the ground receiving stations the recorded impulses are transmitted to a data receiving and archiving facility. On the ground, the transmitted data can be reprocessed with the aid of computers and then made available to the user community as photographic images or, as digital data sets.

14. Electromagnetic radiation incident on an object on the surface of the Earth, interacts with the object at the atomic and molecular level. That portion of radiation which is reflected in the direction of a remotely placed sensor carries information that is intrinsic to the object. In remote sensing applications, the challenge is to identify the object given a measure of the relative amount of reflected radiation. Discrimination between two types of objects becomes easier if measurements are done in several regions of the electromagnetic (EM) spectrum. The regions of the EM spectrum where these remote measurements are performed, have been called "spectral bands" or simply "bands".

15. Photographic film is a sensor of electromagnetic radiation. In conjunction with a camera, film can represent objects in approximately the same manner as they appear to the human eye in every day situations. That is, photographic film is sensitive to radiation in the visible portion of the EM spectrum. A distinction has purposely been made in using the term "image" when referring to a representation of objects produced by a sensor which is not photographic film. A different type of sensor is used to extend detection possibilities to regions of the EM spectrum where photographic film does not respond. The type of sensors used are solid state detectors sensitive to EM radiation in specific wavelength intervals which may include the visible region. In response to radiation received, detectors produce either a voltage or a current that is

proportional to the amount of radiation received in their wavelength band of operation. The output signal is electronically sampled and converted to digital values that maintain a one-to-one correspondence to the original voltage or current value.

16. The digital values are stored on board the satellite for transmission to a ground receiving station. The digital data is corrected for geometric and radiometric distortions and arranged in matrix form, where each element of the matrix corresponds to the radiation received by the sensor from a resolution cell on the surface of the Earth. With the data in this form, it is possible to perform computer-assisted analysis of the image. In order for the user to visualize the image, the range of digital values is typically normalized to fall with the values of 0 to 255. This makes it possible for the image to be displayed in tones of grey, either on a screen monitor or photographic film.

17. Since an image is only a visual representation of the data obtained by the sensor system, its appearance can be arbitrarily controlled. When data from only one band is displayed, it can be shown in tones of grey or in tones of one of the primary colors (i.e. blue, green or red). If more than one band is to be displayed at the same time, each is assigned to tones of a primary color

18. Data gathered by the sensor system in each of many possible bands (e.g. blue, green, red, infrared, panchromatic) are converted digitally to form images in which the intensity of the grey level that represents an object on the surface of the Earth, is related to the amount of solar radiation reflected or emitted by that object in a spectral bands. The spectral resolution of the sensor system (i.e. the width of the band in which a detector respond to electromagnetic radiation) can vary from band to band. The blue band (i.e. from 400-500nm) is generally not used for remote sensing purposes due to the strong scattering of radiation in that interval of the EM spectrum by the atmosphere. Images generated from data gathered in the near infrared portion of the EM spectrum have a lower spectral resolution (i.e. the width of the band in which radiation is gathered, is typically greater).

19. Due to the spectral reflectance characteristics of vegetation, and forests in particular, the bands that are more useful for this application are the near infrared band, where healthy vegetation has a very high reflectance, and the red band, where it has a low reflectance. In order to display both bands in a color composite image, a common assignment of primary colors (blue, green and red) is used. Hues of green are used for data images obtained in the red band and hues of red are used to display images obtained in the infrared band. Due to the high reflectance of vegetation in the infrared, this assignment of colors makes vegetation appear magenta in the composite image. Because the assignment of colors to the red and infrared bands is arbitrary (i.e. not as the eye sees), the final rendition of the image is called a pseudo-color image.

20. For forestry applications, as for many others, better quality information is derived when the analyses and interpretations are based on data obtained in more than one band. The capability to use data that has been digitally enhanced or which includes new bands resulting from linear transformations of the original bands, permits the routine monitoring of large areas and, a finer discrimination among classes of objects present in the scene.

21. With several series of satellites in orbit, an applications specialist can select imagery from among a wide range of spatial (ground distance), spectral and temporal resolutions. For regional studies, a forest manager might use data obtained by sensors carried on board meteorological satellites. The current NOAA satellites carry seven systems to observe the Earth and its atmosphere and provide effective world-wide coverage every 2-3 days. Of these instruments, the Advanced Very High Resolution Radiometer (AVHRR) has multi-spectral characteristics that are very similar to those of Landsat and SPOT. The AVHRR images can be obtained at a 4 km or at a 1.1 km spatial resolution.

22. Information and data from the current NOAA satellites are provided at a low cost, with low resolution and with high temporal frequency. For this reason, this information is particularly interesting to developing countries in need of quality bio mass information to locate so-called "hot spots" or forest areas in danger of environmental harm. Because of the efforts of WMO to coordinate meteorological satellites on an international level, a wide variety of meteorological data is provided when needed to any country. One use of data provided by these satellites concerns a linear combination of the red and near infrared bands. This has proven to be significantly accurate in estimating green bio mass. This linear combination, called the Normalized Difference Vegetation Index (NDVI), is defined as the difference of the infrared minus the red bands divided by the sum of the same two bands. In general, the NDVI values are higher for higher percentage of green vegetation coverage. However, it should be kept in mind that the relationship between NDVI and bio mass is specific for certain vegetation composition and structures.

23. The Landsat programme (United States) began with the launch of ERTS-1 in 1972. This satellite was later renamed Landsat -1 and was followed by Landsats-2 and -3, which had similar sensor systems. The latter were followed by a second series of Landsats -4 and -5 which had new instruments on board. At present Landsat-5 must remain in extended operation due to the loss in space of Landsat-6. Landsat-5 carries two sensor systems, the Multi Spectral Scanner (MSS) which provides 80 m. resolution in the visible and near infrared regions of the EM spectrum, and the Thematic Mapper (TM), which provides 30 m. resolution in the visible and reflective infrared regions of the EM spectrum. As its predecessor, Landsat-5 has a re-visit period of 17 days. Landsat-6 was to have had a 15 m. resolution in a panchromatic band.

24. The SPOT programme was initiated with the launch of SPOT-1 in 1986. This satellite was followed by the launch of SPOT-2 in 1990 and by SPOT-3 in 1993. SPOT-4 is scheduled for launch in 1995. The SPOT series of satellites provide a 10 m. resolution product in panchromatic mode and 20 m. resolution in multi-spectral mode. If necessary, SPOT can provide a revisit period of four to five days over any given point on the surface of the Earth or even more frequently due to the off-nadir pointing capability of its sensors. However, because the angle of observation becomes shallow, both geometric and radiometric distortions become more pronounced at increasing off-nadir angles. SPOT Image, the operator of the SPOT satellites, announced the development of a new generation of satellites, beginning with SPOT-5 to be launched in 1999 and to be followed by SPOT-6 in 2005. The spatial resolution of SPOT-5 will be 5m; both SPOT-5 and SPOT-6 will continue to provide the capability to produce stereoscopic images.

25. Launched by the European Space Agency (ESA) in July 1991, the European Remote Sensing Satellite-1 (ERS-1) has made it possible for specialists dealing with tropical forest areas (frequently covered in clouds), to survey and monitor the forest on a regular basis. This added potential is due to the imaging radar sensor system on board ERS-1. This satellite generates the microwave radiation needed to illuminate the observed scene. Electromagnetic radiation in the microwave range (1 mm. to 1m.) is able to penetrate through clouds and even light rain.

26. ERS-1 is the first mission of the European Remote Sensing Programme, designed as an end-to-end system to serve a large variety of users with a wide range of response-time and applications requirements. The primary mission of ERS-1 is to increase the understanding of ocean processes, to monitor the polar regions and to contribute to the World Climatology Research Programme. However, an increasing number of land-oriented applications are emerging as the international research community gains access to the data.

27. Data from ERS-1 is received by ESA's network of ground stations which include Maspalomas (Spain), Kiruna (Sweden), Fucino (Italy) and Gatineau (Canada) as well as a number of non-ESA ground stations located in both the industrialized and developing countries. User requests for acquisition of ERS-1 data over a particular area of the Earth or requests for specific products of ERS-1 data already acquired, are channeled through ESA's Earthnet Central facility (EECF) located in Frascati, Italy. The EECF catalogues and files ERS-1 data and provides a browse option that is available to the users.

28. Launched in 1992, Japan's Earth Resources Satellite (JERS) is also equipped with a SAR (radar) sensor. However, this sensor system operates in the L band (0.39 - 1.55 GHz). JERS also carries a Visible and Near Infrared Radiometer (VNIR) and a Short Wavelength Infrared Radiometer (SWIR); both instruments provide a spatial resolution of 18 m. x 24 m. The re-visit period for this satellite is 44 days.

29. Although the bulk of radar data that will be obtained over the next 10 years will be in C-band (4.20-5.75 GHz), most of the experience developed to date, has been with radar operating in the X (5.75-10.90 GHz), L (0.39-1.55 GHz) and K (10.90-36.00 GHz) bands. In view of this, efforts are being made by space-related institutions to increase the knowledge base and to enhance the practical experience of the scientific community in the use of C-band data.

30. A project aimed at studying the use of C-band data over moist tropical forests and their environs was conducted over a number of countries in Latin America in 1992. The project, known as SAREX-TF1, involved flying mission using the Canada Centre for Remote Sensing (CCRS) Convair 580 aircraft equipped with radar and electronics to simulate Canada's future Radarsat. The main objectives of this project were to determine the ability of C-band Synthetic Aperture Radar (SAR) to detect and map forest cover types, clearings, burned areas and forest regeneration, extent of flooding, agriculture distribution, natural dams and rivers caused by landslides, and various other types of surface changes. In view of the promising initial results that were obtained, a second project, known as GlobeSAR was initiated in 1993 and will continue during 1994 to extend these experiences to Asia and the Pacific and to Africa.

31. Often it is demographic pressure which drives populations to clear forests in order to cultivate their land. For countries aiming to control the exploitation of their forests, it is essential to have, on a regular basis, adequate monitoring resources at their disposal. However, the acquisition of useful data by the visible and infrared systems described so far, is restricted by cloud coverage. Cloud coverage limits the application of passive systems for forest studies in high latitudes and makes it very difficult to obtain information about tropical forests where it persistently occurs.

32. Satellite remote sensing enables the mapping of forest land and the monitoring of its changes at national, regional or even global levels. Its usefulness in forest mapping is greatly increased if it is based on a multistage concept, depending on the objectives of the particular application, climatic conditions, availability of remote sensing and data processing systems and the cost effectiveness of various options.

33. One of the critical factors for future operational satellite remote sensing applications for global studies will be the number of available ground receiving stations in developing countries. Satellites store on magnetic tape recorders, the data they acquire as they pass over each point on Earth. The satellite transmits the data when it comes within view of a ground receiving station or of a data relay satellite in space. Because the components that had historically failed, have been the on-board tape recorders, the practice is now to dispense with large capacity recorders and transmit the data directly to a ground station. Areas which are not covered by local receiving stations will be less well mapped than areas with local receiving stations. Although the coverage by ground receiving stations is good in most areas of the world, there are large gaps where at present, it is only possible to acquire limited amounts of data. As frequent repetition cycles are very important for forest analysis, the further expansion of the ground station network is of prime importance.

II. FOREST RESOURCE ASSESSMENT

A. Forest Inventories

34. Forests represent a large portion of the Earth's renewable resources. All projections indicate a further decrease of wooded areas because of the needs of a growing world population and because of intensified farming and greater use of wood for energy. Hence, effective forest management requires exact knowledge

about the location and the overall condition of this natural resource in order to best balance the many demands.

35. The acquisition of basic inventory data for forest management is fundamental for the conservation of certain forest ecosystems. In this context, the technology of remote sensing can play a key role in developing an accurate, timely and cost-effective decision making process. Foresters have started to increasingly combine color films, high altitude photography, conventional maps, multi-stage and multi-phase sampling, with satellite maps generated from digital data for forest analysis.

36. Most information needed on forest lands can be readily seen and visually interpreted on various types of aerial and space imagery. The accuracy in identifying types of trees is dependent on the image scale, film type, season which the image was acquired and the complexity of the forest stand. Furthermore, an interpreter's familiarity with the local conditions is also an important factor in the quality of the achieved results.

37. The large potential that remote sensing from space offers is due to the following main characteristics: (i) the large surface area covered by each image; and (ii) the high frequency with which data can be gathered over the same area. Once the data has been acquired it is necessary to extract information from it. That is, the features that are being studied must be identified and quantified. This process is "visual interpretation" when applied by eye to photographic products or computer displays. Alternately, computer algorithms may be used to segment an image into distinct "classes" or target types. In both cases the objective is the same: to identify and differentiate classes of objects that are of interest to the study.

38. The use of computers can enhance and speed the process of extracting the information. The information contained in the images is originally in digital form. To facilitate its display and analysis with a computer-based image processing system, for applications such as forest management, photographic representations of the area being studied, are produced. Results obtained from interpretation of the representations of the area being studied can be excellent. At present, it is possible to purchase high quality photographic negatives or prints at scales of up to 1:50,000.

39. Digital image enhancement techniques improve the visual presentation of the information content of an image. These techniques assist in visual interpretation but do not create any new information. Common techniques include the following: contrast enhancement, spatial filtering, linear combinations of bands and principal component transformations. This step is usually performed to allow the user to better identify a few areas, or test fields in the image that can be used to "train" the computer during the classification process as well as to evaluate the results obtained from a classification. In the best of all cases, the user has complete knowledge of the objects present on the ground in the test fields.

40. Software programs which are used to discriminate the elements present in an image are called "classifiers" and fall into two broad categories which are defined by the degree of intervention necessary by the user. The most commonly used programs are the so called "supervised classifiers". With these, the user identifies homogeneous test areas that are representative of the classes of objects in the image. The classifier then calculates the mean and standard deviation of the picture elements (pixels) in each test field. This process is repeated for each of the spectral bands included (by the user) in the classification process. The set of values of the mean and standard deviation of a class in each of the spectral bands used become the parameters that are used to identify the pixels that belong to a particular class. This set of numbers is also known as the "spectral signature" of the class. When the spectral signatures of all the important classes in the image have been obtained, the program classifies every pixel in the image as belonging to one of those classes. Pixels whose spectral signatures do not match any of the ones provided are usually labelled as "undclassified". If the evaluation of the results is not satisfactory, the user must repeat the process by

redefining the test fields and adding or removing classes. The process becomes interactive until the degree of accuracy is achieved.

41. Unsupervised classifiers require little interaction by the user and are based entirely on mathematical and statistical methods. While this approach makes the classification independent of specific knowledge of the area by the user, it is highly dependent on the mathematical skill of the user. Regardless of which method is used to classify forest areas, or in which part of the world the work is performed, satellite images are used to complement or supplement the information available from other sources as well as to reduce the amount of field work necessary to achieve the goals of a project.

42. With changes in the forest cover occurring so rapidly, it is no longer possible to use old or out of date images to solve present and future environmental problems. The use of some of the new remote sensing tools together with developments in image processing hardware and software, can lead to a much higher repetitive coverage and a more cost effective way of detecting and monitoring the changes of the forested areas on the earth surface. The high speed of a computer makes it very useful in dealing with large data sets. It is also very useful for mapping large geographic areas and for achieving results much more rapidly than standard interpretation techniques. The data accumulated during the image processing and classification process can best be put to use if they are incorporated in a system capable of efficient data storage and expedient data processing such as Geographical Information Systems (GIS).

43. The acquisition of basic inventory data is fundamental to forest management as well as to the conservation of certain forest ecosystems. Once these data are entered into a Geographic Information System, maps showing general species distribution, volume estimations or general forest conditions can be displayed and printed.

44. Data over an area can be updated over time as satellites provide high repetitive coverage. Some satellite imagery is available in a wide range of spectral, spatial and temporal resolutions. Changes in the distribution of forests can be recorded and analyzed to map broad forest types and to detect and delineate major forest changes.

45. As deforestation in South and Central America, Africa and Asia has become a significant international concern, basic inventories of tropical forests have become an urgent necessity. In this context, it is only airborne and satellite imaging technology that can provide the capability of rapidly monitoring the evergreen rain forests.

46. To inventory the vast areas of the tropics, a combination of sophisticated remote sensor platforms must be used. Coarse spatial resolution scanners (e.g. AVHRR) with a high temporal resolution are needed to reduce data volumes and to identify the areas of concern. In suspected or known problem areas, SPOT and Landsat data can be used for recording higher resolution spectral and spatial details. The high probability of full cloud coverage, a persistent problem in the tropics, can be overcome with the radar sensors.

47. In addition to remote sensing, spatial positioning technologies such as the newly developed Global Positioning Systems (GPS), can be used as a real time mapping tool to update GIS inventory data. In remote tropical areas with no adequate maps, GPS systems can represent a powerful tool to establish ground control points and to rectify satellite images for further processing.

B. Damage Assessment

48. Forest damage is described as any type or intensity of an effect, on one or more trees, that temporarily or permanently reduces their financial value, or impairs or removes the biological ability of growth and

reproduction. Space imagery can provide adequate and rapid assessment for different stages of stress due to pollution, lack of water, insect damage, and other causes.

49. Space imagery is also useful for pre- and post-forest fire mapping. A successful fire management programme is dependent on the information that has been gathered and the action taken before a fire starts. True and false color images can provide information for inventories concerning existing conditions, major topographic features and special hazards.

50. While an initial inventory of forest resources stored in a GIS is an important step, changes that occur in these ecosystems need to be recorded and monitored. Changes can result from sudden events or disturbances, such as massive deforestation or the extensive use of pesticides, and lead to destructive patterns over vast areas of forested areas.

51. Since deforestation is a continuing process, efforts to inventory and monitor changes have to be performed perpetually. To overcome the uncertainties about actual rates of deforestation, accurate and up to date monitoring schemes have to be developed.

52. Deforestation is a complex phenomena resulting from the interaction of climatic, human and geographic factors and it requires and will continue to require, consistent observations over long periods of time. Deforestation and other environmental concerns cross all national boundaries and, it is absolutely necessary to monitor the continents on a regional and continental scale. In the future, the information gained over this period of time can in the future lead to precautionary measures and hence minimize the severity of impacts on the forest environment.

53. Gradual forest decline is another type of change that can be monitored. Vegetation is extremely sensitive to stress factors and susceptible to changes in moisture, temperature as well as anthropogenic factors such as air pollution. Remote sensing offers the means to monitor the magnitude and the rates of long term forest decline.

54. Landsat TM and SPOT data can be used to assess and monitor damage in coniferous forests and to establish the damage patterns. By comparing these patterns with older data, damage factors associated with micro-climate and weather patterns being responsible for forest decline, can be separated from anthropogenic causes.

55. In this context, the European Community and the European Space Agency initiated an ambitious project called TREES (Tropical Ecosystem Environment Observation by Satellites) to monitor the global forest cover and the rate of deforestation. TREES will combine data from many sources including ERS, SPOT, Landsat and the NOAA meteorological satellite to monitor tropical forests.

56. In Brazil, fire is extensively used for agricultural practices, pasture removal and deforestation. Although the environmental concerns about its use is very strong, no estimates of fire frequencies, locations or extent have been available until now. For this reason, a system for the operational detection of fires in near real time using AVHRR data, has been developed.

57. The AVHRR system requires relatively simple Personal Computer technology and straight forward fast processing. Users receive telex messages that give the coordinates of fires, and maps of regions with a high probability of future fires. Thousands of fires have been identified and many of them were controlled through the information provided. All together, the majority of the fires were found by ground crews within a few meters of the estimated coordinates and hundreds of penalties have been given to persons starting unauthorized fires.

58. In Indonesia, deforestation of tropical forests is mainly due to forest logging and shifting cultivation. With the help of remote sensing and the combination of visual and digital analysis, it has become possible to monitor and to assess the rapidly growing process of deforestation in local tropical forests.

59. In Indonesia, satellite data and remote sensing contribute significantly to regular inventories of the land cover and to the monitoring of periodic change in forest cover. By combining different satellite data, a good synoptic view of this area is achieved and forest density, which is a very important indicator for certain analyses to monitor this natural resource, can be determined.

60. For all of these applications, the greatest value of remote sensing in tropical forests lies in the possibilities to differentiate and recognize various plant communities. Satellite images for applications in forestry can be a useful tool in reconnaissance surveys and give a good indication for the presence, absence or modification of local forested areas.

61. The achieved information is of high value and can be obtained at a relatively low cost. In addition to general vegetation mapping, remote sensing also facilitates the location of timber areas, the layout of roads, the determination of distances to mills and outlets and other information essential to forest land management.

C. Productivity Assessment

62. Important actions that have to be considered for forest resource assessments include efforts to identify biophysical conditions that could be suitable for the regeneration of tree species. This information is important for establishing tree plantations for afforestation programmes, for re-establishing endemic species following severe over-utilization and for timber harvesting. Remote sensing data can be used for the aforementioned investigations and the information obtained from assessing the potential productivity of a site can be utilized to manage it for an optimal harvest.

63. Climatic criteria such as mean annual rainfall, rainfall regime, length of dry seasons, mean, maximum and minimum temperatures and mean annual temperature can be combined with information derived from satellite images, and lead to identifying locations where plantation species could be successfully cultivated. This approach is suitable for regional but also for continental and global scales.

64. As a part of a land resource inventory in Nepal, data on land use, topography, land systems and land capabilities were collected and, combined with available climatic information and terrain elevation data, the investigated region was subdivided into certain categories. With this technique, it was possible to identify locations that satisfy specific climatic criteria for cultivating plantation species.

65. The results of these investigations are of interest for afforestation programmes that are initiated to overcome chronic fuelwood and fodder deficits. Reasons for this shortcoming are a low tree seedling survival, heavy grazing, difficult climate conditions and poor soil and site conditions. The created maps can provide a crude basis for matching tree species with appropriate environments and new crops and cropping systems such as fruit and vegetables with the most appropriate site conditions.

III. RESOURCE MANAGEMENT AND ENVIRONMENTAL MONITORING

A. Forest Management

66. In forest land management, remote sensing finds one of the most important applications in the field of resource management. Unlike extensive timber volume inventories and damage surveys where techniques and results are precisely defined, its chief value lies in the routine day-to-day applications to ground management of forested land.

67. The use of satellite images gives wildlife and forest managers a synoptic overview of the large areas occupied by a forest. Thus, managers can dedicate more time to plan and to make decisions rather than spending a significant portion of their time travelling to different parts of the forested areas. Land corners, roads, timber stands and other features can be located without difficulty, making the task of dispatching timber markers, surveyors and other forestry personnel more efficient. Likewise, planning and supervising logging operations, road construction, fire prevention and suppression and timber stand improvement work can be done more cost effectively.

68. For all forest management activities, the continuous collection of forest inventory data and the monitoring of changes is critical. Because of their repetitive coverage, satellite images, can also serve as permanent records of timber conditions at the time of detection and can be compared with images of subsequent times.

69. The collected data can finally be incorporated into a GIS and serve as models to guide timber harvesting, fire management activities, or predict fuel wood and other resources supply. Other priorities, such as providing sufficient wildlife habitats, ensuring recreational opportunities and minimizing visual impacts of harvesting, can be achieved as well.

70. The use of remote sensing in timber harvest planning can start several years before the actual harvest. First, the overall plan is revised and a decision concerning the place where the cutting will take place is made. A number of possible routes through the selected areas can then be selected based on the images. Finally, after examination, the most promising areas of timber harvesting are chosen.

71. Once the general area of the proposed timber harvest is identified on a satellite image, topographic features such as cutting boundaries, logging methods, soil stability and road layout can be studied in more detail. With the help of remote sensing, most clear cut type timber harvesting can be performed, and, as a whole, areas can be visualized. These options minimize the possibilities of having a group of illogically shaped units on the final harvest cut.

72. Effective timber management focuses on efforts to provide a continuous supply of trees for optimal and economical wood production. In the recent past, foresters have relied on models for planning optimal harvests. These models are sufficient for defining and developing spatial management strategies for wood supply but lack consideration of the geographic location of forests and are insufficient in defining wildlife sensitive areas and operational and economically acceptable management structures.

73. By integrating remote sensing data with data from other sources (i.e. cartography) in a GIS, it is possible to incorporate these spatial components and create more accurate simulation models for harvest planning. In some cases, the modelling capabilities of a GIS may be used directly to aid the decision making process used for timber harvesting; in other cases external models can be linked to a GIS database. This results in the so-called Decision Support Systems or Spatial Decision Support Systems.

B. Fuel Wood Supply

74. The availability of fuel wood for local and regional use is an important factor for forest management issues throughout the world. The combined use of satellite remote sensing and GIS can contribute significantly to assessments of fuel wood supply and demand, and offer the potential to predict future needs.

75. As a part of a land resource mapping project in Nepal, the fuel wood sufficiency for the 75 districts in the country was evaluated and mapped by using satellite imagery and computer technology. This evaluation was part of a larger resource overview for national land use planning which included research on food and fodder resources.

76. The fuel wood supply and production was estimated by using field yield data for each forest type included in the inventory, combined with other information concerning the distribution of grassland, shrub and human population density. With the help of GIS computer technology, it was possible to calculate fuel wood supplies and estimated demand and to develop for each area, surplus or deficit figures.

77. The infrared and red image bands of the Landsat TM and MSS imagery were very useful for producing vegetation bio mass maps which provided good indications of the balance between supply and demand for fuel wood. By comparing these woody bio mass supplies with village locations and population distribution, a map illustrating areas in surplus, areas in balance, and areas in deficit of fuel wood was produced.

78. Future figures were then computed on the basis of an unchanged resource base and a drastically increasing population of persons and livestock. The results of the fuel wood assessment were also combined and compared with the fodder and food assessments in order to achieve an overall evaluation of the potential resource deficit if no action were taken.

79. Overuse of wood for fuel and uncontrolled deforestation can be dangerous for countries relying heavily on timber exports to finance their economic development. In Thailand, formerly a major exporter of industrial wood, this has led to rapidly increasing import bills for manufactured wood products.

80. All these aforementioned examples represent incontrovertible evidence of the negative impact of tropical forest removal on soil degradation and desertification, erosion, increased water run off and flooding, and spread of human and plant diseases via colonization. This leads consequently to increased food insecurity and declining water quality.

81. Furthermore, the costs of hydropower and irrigation projects rise as dam reservoirs become filled with silt from erosion. This causes hardship for a huge and increasing population, which is suffering from shortages of fuelwood and fodder and a declining quality of life.

82. Today, a greater number of governmental and nongovernmental organizations are well aware of this problem and are increasingly willing to take actions to reverse the trends as is shown by drastically increasing the official development assistance for forestry. It is in this context that a project on training in monitoring deforestation using satellite data for sustainable environmental management was set up by the South East Asia Ministers of Education Organization (SEAMO) and France.

83. This project is at the same time regional and national in scope concerning Brunei Darussalam, Indonesia, Malaysia, Philippines and Thailand. The technical objectives of the project are to carry out small and large scale forest surveys with the help of remote sensing techniques, and to transfer existing know-how to the forest agencies in those countries.

C. Monitoring and Controlling Deforestation

84. Forests all over the Earth surface are disappearing at the rate of thousands of square kilometers per year. Although not limited to them, deforestation is laying waste to a valuable natural resource in developing countries and is driving countless plant and animal species to extinction. Furthermore, it may well have a significant effect on the world climate.

85. Among the agents of devastation are inefficient commercial logging operations, overuse of fuel wood and the conversion of forested areas to cattle ranching and agriculture. Many of those actions are driven by government policies resulting from severe economic pressures affecting to a greater degree, the debt-burdened, least developed countries.

86. The destruction of tropical forests is a more serious problem now than a decade ago, based on recent estimates from remote sensing data and careful field surveys. In India, studies have shown that the actual rate of deforestation is ten times higher than that estimated by the Food and Agriculture Organization of the United Nations (FAO). Moreover, satellite images show that areas legally designated as forest land, are already virtually treeless.

87. Deforestation at this rate poses extreme risks to natural systems and it is estimated that the rate of carbon dioxide in the atmosphere will increase significantly and contribute to the buildup of greenhouse gases.

88. A sense of crisis is emerging in the tropics as governments recognize that rapid deforestation represents a waste of valuable resources and represents serious economic loss. Some governments have yet to take action. In Thailand however, all commercial logging was recently banned, despite the protests of influential concession holders. In only three years of undisturbed logging, the forest coverage declined from 29 to 19 percent of the land surface area causing landslides which destroyed around 40,000 homes.

89. In Brazil, where little timber is extracted before forest land is cleared by burning, it is not only the loss in commercial timber but also the fact that many of the established ranches are inefficient. Bare soil remains unprotected against heavy tropical rains and is being washed away thus leading to soil erosion. Hence the soil becomes unsuitable for farming.

90. According to the latest study of FAO a total of 154 million hectares of tropical forests have been lost between 1981 and 1990 thus continuing the increased pace of deforestation over the past 40 years.

91. The FAO report which uses high resolution satellite data, put the total area of the world's tropical forests at the end of 1990 at 1,756 million hectares, which equals 37 percent of the land surface area, and estimated the annual deforestation rate at 15.4 million hectares. This study shows a dramatic increase of deforestation in Asia and a less severe increase in Africa, Latin America and the Caribbean.

92. This uncontrolled loss of tropical forests results mainly from population growth, rural poverty and the resulting need to clear land for agriculture. In this context FAO strongly supports compliance with the Forest Principles and the action programme set out in "Agenda 21" of the Rio Earth Summit.

93. According to a recent study commissioned by the International Tropical Timber Organization, not even one tenth of one percent of the remaining tropical forests are being managed for sustained productivity. It must be acknowledged that forests are essential to economic development and at the same time, have an important role in maintaining ecological balance.

94. Apart from sustainable development, forests have a great impact on a stable biosphere and on the global climate, and it is the technology of remote sensing that provides a cost effective method for monitoring global and regional environmental degradation. New forms of international cooperation to halt the destruction of rain forests and continuing efforts in monitoring the earth's surface conditions and its changes will be necessary to manage these global environmental problems.

D. Environmental Monitoring

95. To monitor resources that are sensitive to environmental conditions and subject to change over a relatively short period of time such as forests, remote sensing data must be reliable and frequently available. Remote sensing instruments on board Earth observation satellites (e.g. SPOT and Landsat) provide coverage over any given area every few weeks and do not capture data frequently enough to allow such monitoring.

96. Meteorological satellites, however, such as the Advanced Very High Resolution Radiometer (AVHRR) of the United States NOAA can at a coarser resolution provide the necessary repetitive interval. To understand on-going changes, it is necessary to monitor the environment at regional and continental scales, and a trade-off must be made with the detail to which environmental information can be applied.

97. Land vegetation and forests are an intrinsic part of the terrestrial ecosystem and as such, it influences and responds to other components of these ecosystems. This means that vegetation exhibits strong dynamic behavior in both spatial and temporal dimensions.

98. Satellite observations portray the vegetation condition at the specific time of the satellite overpass and this information must be combined with ground and aircraft observations and models of vegetation behavior in order to obtain a comprehensive, quantitative picture of the vegetation condition and their response to changing environmental conditions.

99. In this context, vegetation can be understood in terms of several interactions between climate, soil, landform, fauna and water. The study of forests with the technology of remote sensing and the further use of these data in GIS allows for the development of techniques to identify locations of vegetation change and quantification of this change. Furthermore, methods to determine the total phytomass and to estimate the annual net primary productivity and the net change in carbon storage for the vegetation can be calculated as well.

100. The timely availability of accurate information now allows warning for the onset of droughts, storms, locust plagues, forest diseases and the like that can be foreseen. This provides time to take necessary precautionary measures thus minimizing the severity of damage suffered by forests. Many natural disasters which have been graphically portrayed by the world media in the last few years, would have been less severe if operational remote sensing and GIS had already been in place.

101. However, many programs using remote sensing data for environmental monitoring are already in place. The Famine and Early Warning System (FEWS) and the Africa Real Time Environmental Monitoring Using Imaging Satellite (ARTEMIS) of FAO provide much needed information and are considerably successful.

102. Modeling of the deforestation impact on climate change and the environment has shown that, on a regional scale, the temperature of the atmosphere could increase, and that the evapotranspiration and precipitation could decrease considerably. With less rain and more heat, significant changes in vegetation types would also likely occur. The dry season would become much longer if most forests are cleared, owing to the decrease in precipitation. There would be a large negative impact on tropical rain forests since it can only exist in an environment with short dry seasons and a level of high ground moisture. Additionally, most tropical forest plant species cannot resist the burning which occurs when the climate has one long dry season. Thus with the conversion of forest to pasture, followed by the interruption of human activities, the forest would be unable to re-germinate because of these new climatic conditions. Other types of vegetation would take its place.

IV. FUTURE PROSPECTS

103. Satellite remote sensing technology and applications techniques using multi-spectral scanners in the visible and infrared spectral regions are quite well developed and are not likely to change dramatically in the near future. The Landsat and SPOT satellites are expected to continue providing data, as are meteorological satellites. There is, however, great potential for increased applications of remote sensing for forest applications in developing countries. Among the obstacles that need to be overcome are the lack of persons trained in image interpretation and image processing, the high cost of data, particularly for extensive repetitive coverage, and the lack of regular coverage because of persistent cloud coverage.

104. Applications of satellite radar to forest resource inventories should be developing rapidly in the next few years as the data become widely available for the first time. In addition to the ERS-1, JERS and Almaz Satellites which are providing data on a quasi-operational basis, Canada's Radarsat will soon be providing data. As with other remote sensing satellites, the extent to which the data are used will depend on the availability of Hard- and Software platforms, the availability of trained interpreters and the availability of data at affordable prices.

105. The development of computer based geographic information systems for integrating data from different sources will increase with the practical use of satellite data. A GIS is designed to accept large volumes of spatial data, derived from a variety of sources, and to efficiently store, manipulate, analyze and display these data according to user defined specifications.

106. With these developments in the 1990s, space technology can be expected to be applied more widely, including applications for forest resource management, and to make an increasing contribution to the social and economic development of countries throughout the world. The technology has become mature enough that it can be relied upon as regular resource data, providing far more information than ever possible by conventional surveying sources. With this wealth of information, individual nations can look to those data for planning and management information.